The IEEE 1451.4 Proposed Standard And Emerging Compatible Smart Transducers and Systems

By
Torben R. Licht, Brüel & Kjær Sound & Vibration, Denmark

ABSTRACT

Over the last decade a number of instrument busses and new ways to communicate with transducers have been introduced, but most of these methods have been useful only to small segments of the transducer community.

The IEEE transducer community recognized the need for a general standard that would make life easier for the transducer community, and began work on the 1451 series of standards.

Furthermore, the ready availability of off-the-shelf integrated circuits for implementing built-in electronic data sheets in small transducers represents a large step forward.

This paper will describe the latest development within the IEEE1451.4 standardization effort and will discuss the opportunities and challenges of building systems with Plug and Play transducers, downloading calibration data and exploiting the extended functionality.

INTRODUCTION

The ever-increasing capabilities of electronics and computers and the widespread availability of networks can be exploited to make possible the use of large numbers of transducers to measure, characterize and help model many structures. This creates an increasing demand for "bookkeeping" of transducer data with the associated error probabilities.

Therefore the drive to get transducers with built-in identification, data (e.g. calibration factors) and even extended functionality has increased sharply over the last few years. The IEEE transducer community, in a concerted effort with NIST, started the work on the 1451.4 standard to fulfill the demands and needs of the changing industry The main objectives of this standard are to:

- Enable plug and play at the transducer level by providing a common IEEE 1451.4 Transducer communication interface compatible with legacy transducers.
- Enable and simplify the creation of smart transducers.
- Facilitate the support of multiple networks.
- Make a bridge between the legacy transducers and the networked transducers
- Enable implementation of smart transducers with minimal use of memory

The existing fragmented sensor market is seeking ways to build low-cost smart sensors. Many implementations of mixed-mode (i.e. able to work both in analog signal transmission mode and in digital communication mode but not simultaneously) smart sensors have been developed, but market acceptance has been slow because of the lack of a standard. A universally-accepted mixed-mode transducer interface standard would not only allow for the development of compliant smart sensors and actuators, it could also lead to lower development costs. Therefore, the objective of this project was to develop a *Mixed-Mode Transducer Interface Standard* that could enable the choice of transducers independent from the choice of networks. This relieves the burden from the manufacturer of supporting a cross product of sensors for multiple networks, and helps to preserve the user's investment if it becomes necessary to migrate to a different network standard.

There was previously no defined common digital communication interface standard between mixed-mode transducers and Network Capable Application Processors (NCAPs). Each transducer manufacturer defined its own interface. Consequently transducer manufacturers could not support all of the control networks for which their products might be suitable. It was concluded at a transducer workshops held in 1997 that a common *Mixed-Mode Smart Transducer Interface Standard* be proposed. This common interface allows the transducer manufacturers to more easily support multiple control networks.

This standard simplifies the development of networked transducers by defining hardware and software blocks that do not depend on specific control networks. The standard describes the following:

- An IEEE 1451.4 Transducer containing a Mixed-Mode Interface (MMI) and a Transducer Electronic Data Sheet (TEDS).
- The MMI which is a two-wire, master-slave, multi-drop, serial connection. MMI requires a single

master device to initiate each transaction, with each slave or node according to a defined transaction timing sequence. The MMI uses two wires for power supply, time-shared analog signal and digital data connection.

- The TEDS which is fixed and dynamic data contained in one or more memory nodes on the MMI. (NOTE - Digital interface is not part of TEDS templates).

- A Template which is software object describing the data structure of TEDS. It is implemented in the Description Language and resides in the Transducer block (T-block).

- The Description Language which is a scripted and tagged language providing a standard method to describe the functionality of IEEE1451.4 Transducer.

- A Transducer Block which is a software object describing the IEEE 1451.4 Transducer. It resides in the NCAP, which is the master device (e.g. an instrument or data acquisition system).

The working group has defined the following to facilitate the creation of plug and play systems containing transducers:

- TEDS data structure. A Description Language to describe the functionality of the transducer.

- A set of TEDS-templates for various transducers.

- The Mixed-Mode Interface to access the TEDS.

- A T-block to access, decode and encode TEDS using the Description Language.

The TEDS residing in the IEEE 1451.4 Transducer, provides self-describing capability. The TEDS contains fields that describe the type, operation, and attributes of one or more transducer elements (sensors or actuators). By requiring that the TEDS be physically associated with the IEEE 1451.4 Transducer, the resulting hardware partition encapsulates the measurement aspects in an IEEE 1451.4 Transducer, while the application-related aspects can reside in the NCAP or alternatively be stored in the TEDS

The IEEE 1451.4 Transducer is a sensor or actuator with typically one addressable device, which here will be referred to as a node, containing TEDS. The digital communication can be used to read the TEDS information and to configure an IEEE 1451.4 Transducer.

The T-block is responsible for communication with the IEEE 1451.4 Transducer. To perform this task external information is required. This information is contained in the Description Language and associated files. The Description Language can be used as an application for communication and configuration. The Description Language does not reside in the IEEE 1451.4 Transducer.

An IEEE 1451.4 protocol is used to separate the time critical part of the communication of the IEEE 1451.4 interface from the T-block. The T-block object located in the NCAP handles the interpretation of the TEDS data for the end user. Further processing of the data may take place both in the NCAP and in other processors in larger systems. The NCAP includes an IEEE 1451.1 object model with an IEEE 1451.4 T-block.

The IEEE 1451.4 Mixed-Mode Interface can be used for control networks and data acquisition in a variety of applications such as portable instruments and data acquisition plug-in cards for PCs.

The standard does not constrain competitive differentiation in areas of quality, feature set and cost, and at the same time offers the opportunity to design to a common interface, which can be used in a wide variety of applications.

SOME DETAILS FROM THE P1451.4 PROPOSED STANDARD

Foundation

An IEEE 1451.4 Transducer contains a Transducer Electronic Data Sheet (TEDS) and a Mixed-Mode Interface (MMI). The context for the mixed-mode transducer and interface is shown in Figure 1.

An IEEE 1451.4 Transducer may be used to sense or control multiple physical phenomena. Each phenomenon sensed or controlled shall be associated with a node.

If more than one node is included in an IEEE 1451.4 Transducer, one of the nodes must have a memory block that holds the Node-List. A Node-List contains the IDs of the other nodes.

An IEEE 1451.4 Transducer has no more than one Node-List. If there is only one node inside an IEEE 1451.4 Transducer, there is no Node-List

Each IEEE 1451.4 Transducer is connected to an IEEE 1451.4 Mixed-Mode Interface.

Each Mixed-Mode Interface can have several IEEE 1451.4 Transducers attached provided they are capable of acting in a passive mode.

To communicate with the nodes inside an IEEE 1451.4 Transducer with shared wires, the IEEE 1451.4 Transducer is switched into “IEEE 1451.4 mode". This can be achieved by reversing the polarity. While in “IEEE 1451.4 mode”, the shared lines are used for the digital communication described in this standard and other uses are inhibited. If separate wires are used for the IEEE 1451.4 communication, any other communication can take place simultaneously.

Multiplexing

Multiple IEEE 1451.4 Transducers with switch nodes can be connected in a multi-drop configuration with maximum one of these Transducers in “active” mode and the rest in “passive” mode. The switch nodes can be used to change the functional mode of each IEEE 1451.4 Transducer.

Node-Lists are used to specify which nodes correspond to which IEEE 1451.4 Transducer(s). This is needed if two (or more) nodes are connected to the same IEEE 1451.4 Mixed-Mode Interface. A Node-List is not included if an IEEE 1451.4 Transducer contains only one node. If more nodes are present and no Node-List is found, then each node will be an IEEE 1451.4 Transducer. This permits e.g. a single thermometer node to be an IEEE 1451.4 Transducer.

The TEDS must contain information about the type of transducer which is connected, e.g. if it is a sensor or actuator and which physical unit is being measured.

If there are more nodes with memory, the memory shall be considered as contiguous, ranked by this list of nodes.

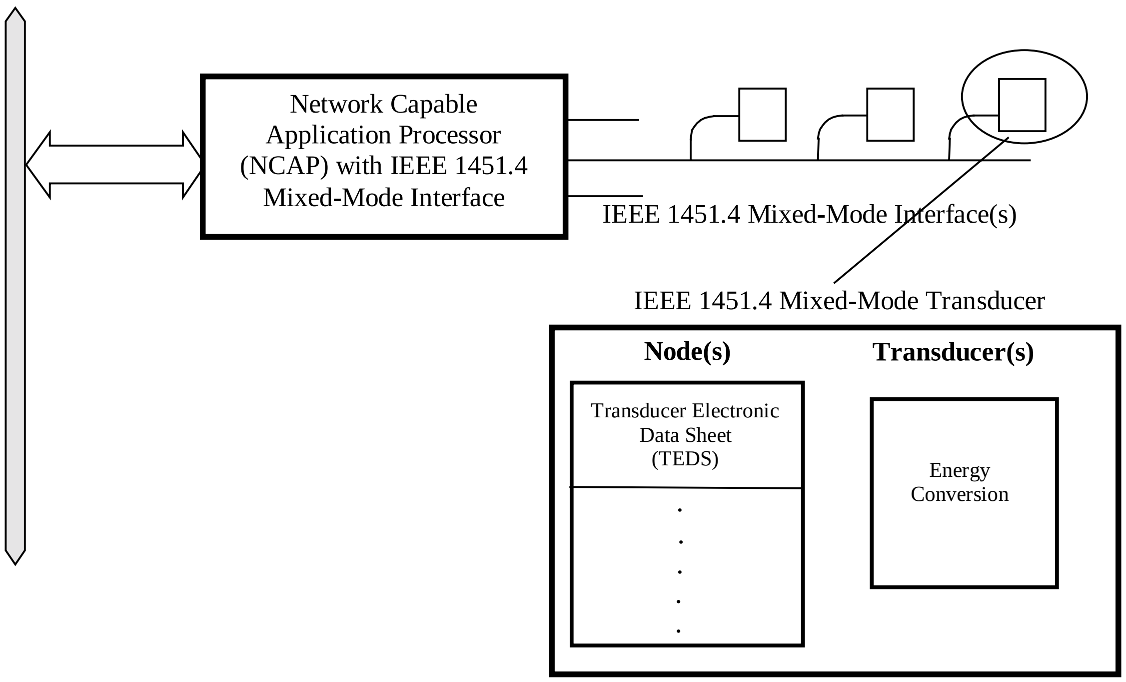

Figure 1. Context for the Mixed-Mode Transducer and Interface

Communication to an IEEE 1451.4 Transducer

Configuration of the IEEE 1451.4 Transducer can be performed by the use of dedicated nodes. The description language contains the information needed to change the configuration.

For example, configuration changes allow:

- Self-test
- Reset of transducer
- Multiplexing between transducers in an IEEE 1451.4 Transducer
- Gain shift in an IEEE P 1451.4 Transducer
- Change of filter settings in an IEEE P 1451.4 Transducer

Communication to several IEEE 1451.4 Transducers on one IEEE 1451.4 interface

Enabling or disabling of the analogue function of the different IEEE 1451.4 Transducers permits several IEEE 1451.4 Transducers to be connected to the same IEEE 1451.4 interface. The Node-List groups the nodes for each IEEE 1451.4 Transducer. This makes multiplexing possible.

The description language

The Description Language described in the standard contains the necessary rules for creating unambiguous Description Files. An interpreter can then handle these and the binary output stored in the transducer. Afterwards the binary content of the transducer can be read and interpreted into the original specifications. A TEDS editor has been created to facilitate these actions. This is however not a part of the standard. Figure 2 shows these relations graphically.

THE FAMILY OF IEEE 1451 STANDARDS

The proposed standard defines an interface for mixed-mode transducers (i.e. analog or other transducers with digital output for control and self-describing purposes) as part of the P1451 family of standards (see Figure 3).
It establishes a standard that allows mixed-mode transducers to communicate digital information with an IEEE P1451 compliant object. Both sensors and actuators are supported and the existence of the P1451.4 interface is invisible from the network's viewpoint.

It is the intent that all of the standards in the IEEE 1451 family can be used either as stand-alone or with each other. For example, a "black box" transducer with a P1451.1 object model combined with a P1451.4 compliant transducer is within the definition of the P1451 family specification. The IEEE P1451.4 interface is needed both to allow the use of existing analog transducer wiring, and also for those demanding applications where it is not practical to physically include the network interface (NCAP) with the transducer. Examples of the latter include very small transducers and very harsh operating environments.

Each P1451.4-compliant mixed-mode transducer will consist of at least one transducer, the Transducer Electronic Data Sheet (TEDS) and interface logic required to control and transfer data across various existing analog interfaces. The transducer TEDS are minimized and defined such that it contains enough information for the higher level P1451 object.

The IEEE P1451.4 proposed standard allow analog transducers to communicate digital information with an IEEE P1451 object. The standard defines the protocol and interface. It also defines the format of the transducer TEDS. The standard will not specify the transducer design, signal conditioning, or the specific use of the TEDS.

An independent and openly defined standard reduces the risk for potential users, transducer and system manufacturers, and system integrators. This will accelerate the emergence and acceptance of this technology.

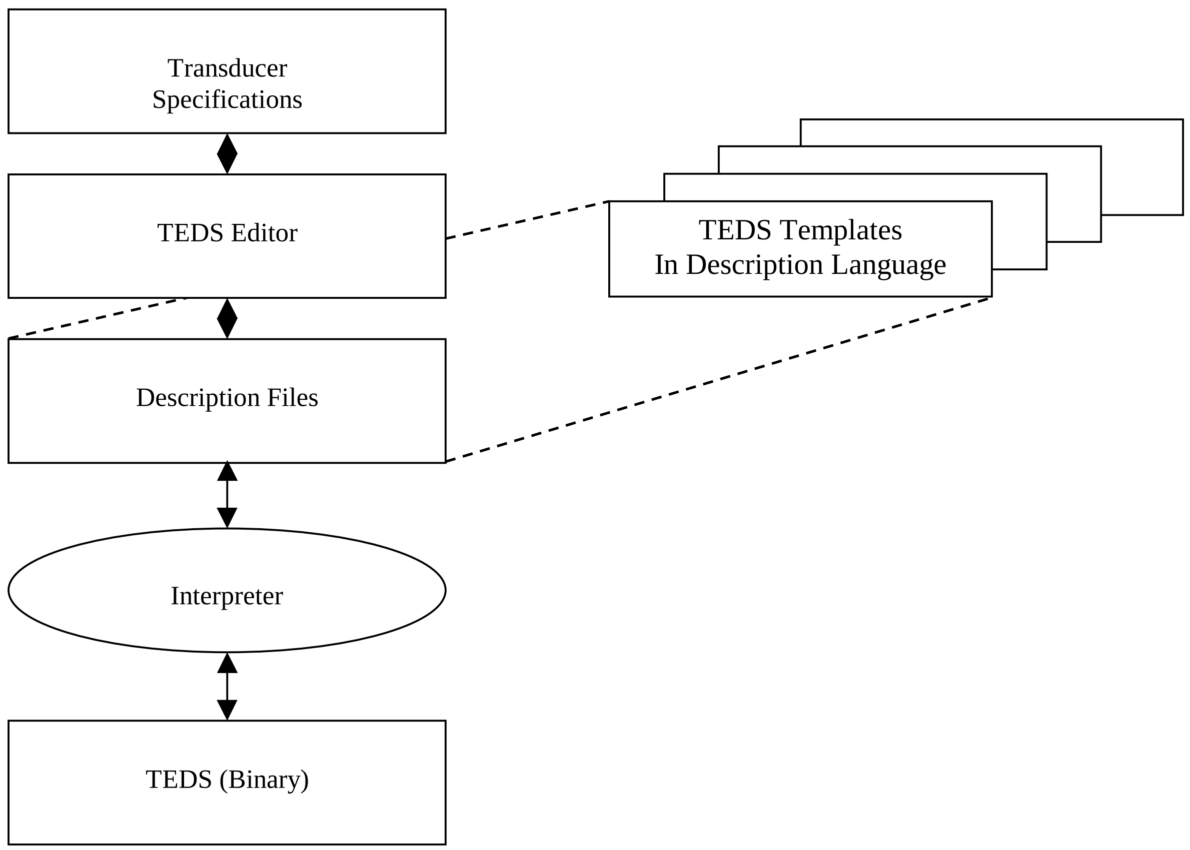

Figure 2. Description Language use

IMPLEMENTATION

The two-wire interface demands are set e.g. by the standard co-axial interface used for accelerometers with built-in constant current line drive (i.e. ICP®, DeltaTron®, Isotron® and several others) amplifiers. Once the requirement for a two-wire interface is fulfilled, the implementation in other transducers, where separate wires are available, poses no problems. By using a reversed polarity technology for switching between the normal analogue mode and the digital communication mode, the chosen principles from the MicroLAN™ interface fulfils all the stated needs.

This technique enables switching between the analogue and the digital mode, using only two standard diodes. Reversing the polarity performs the switching. The principle is shown in Fig. 4, which also shows the simplicity of the receiving device. Primarily an additional supply (here the COM port is used) is needed for supplying the negative voltage for the ID-device. The microcontroller or PC maintains the communication and translation of signals to and from the memory component(s) in the transducer

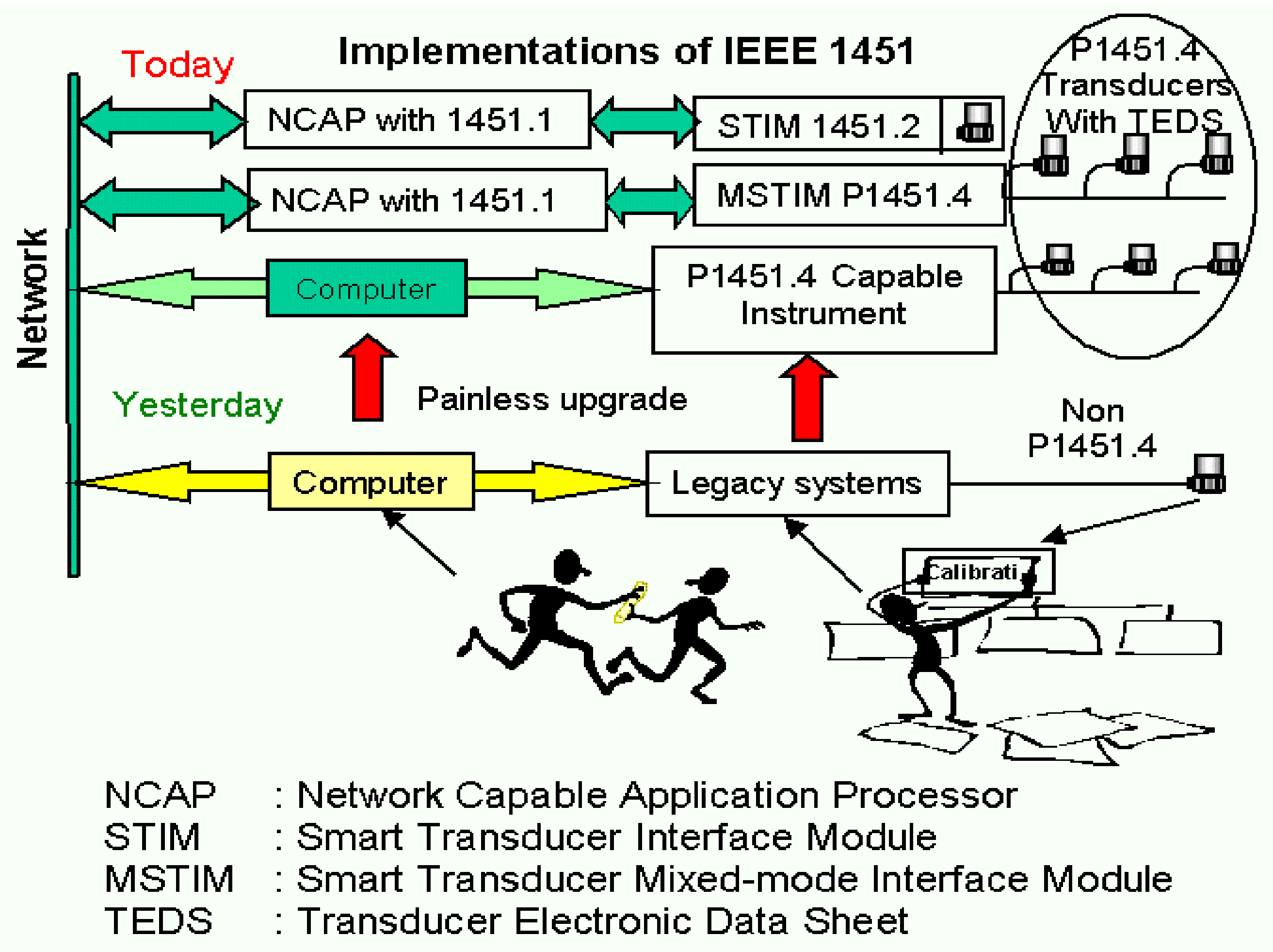

Fig. 3. The P1451 family of standards

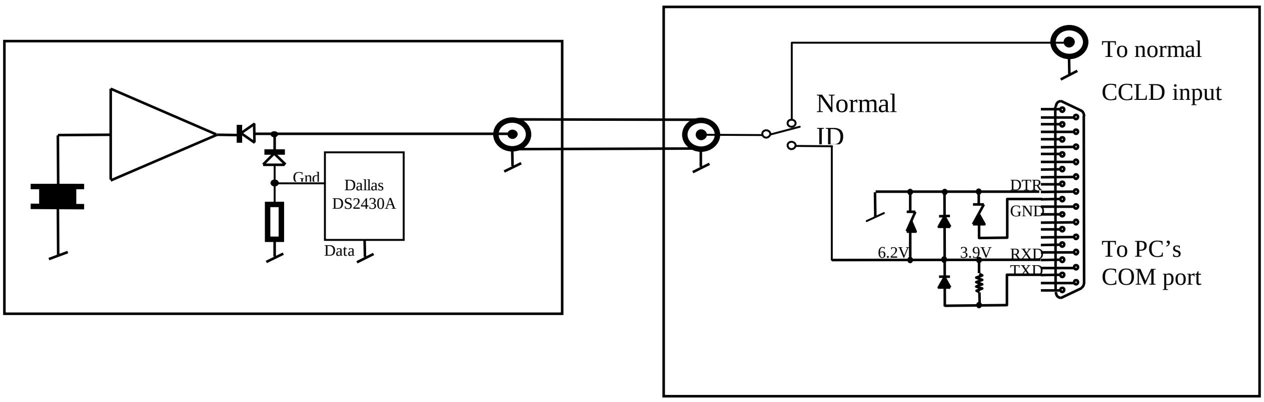

Fig. 4. Principle of implementation of integrated identification with PC support for Constant Current Line Drive (DeltaTron®, Isotron®, ICP® etc.) transducers. Transducer (left) connected via a co-axial cable to interface (right)

BENEFITS OF IEEE 1451.4 FOR THE USER

In order to describe precisely a given measurement system, all individual components (transducers, preamplifiers, conditioning units, analyzers) including their settings must be known. In multichannel systems in particular, the customer faces a number of problems including:

- Long set-up times
- Validation of the position of the transducers

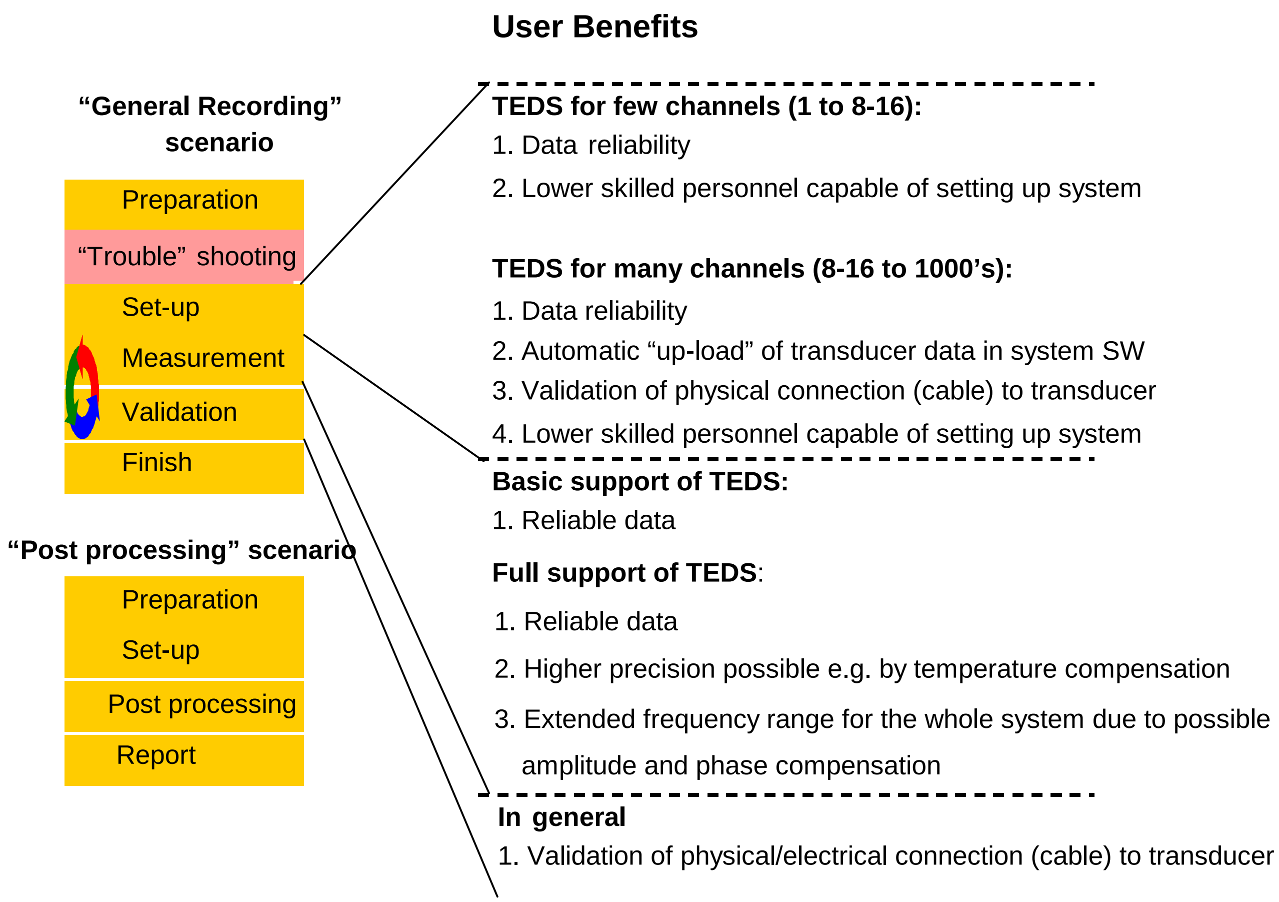

Fig. 5. TEDS impact on the measurement process

The implementation of IEEE 1451.4 transducers and systems reduces these problems to a minimum by incorporating essential identification data (such as type and serial number) within the transducer itself in a Transducer Electronic Data Sheet (TEDS) together with calibration data such as sensitivity thus introducing “plug and play” functionality into the system.
Figure 5 shows this graphically.

STATE OF THE ART PRODUCTS

The standardization and the available memory and communication devices has led to the implementation of a number of products (more than 50 from B&K alone) with functions such as:

<u>Identification</u>
This feature is the main driver for obtaining communication with a transducer. By using the memory very efficiently, practically all relevant information is stored inside the transducer, so the needed data are always at hand. This is practically a duplication of the calibration chart.

<u>Gain adjustment</u>
Transducers often consist of two items. A device to transform the physical properties into an electrical signal (e.g. piezoelectric discs and a seismic mass in an accelerometer) and a conditioning circuit. This transforms the output impedance and the signal level to make the signal of practical use outside the transducer. The dynamic range of this electrical circuit is frequently much smaller than the dynamic range of the physical transducer (for an accelerometer 160 dB are reduced to about 120 dB). This makes a compromise necessary when constructing the transducer. With the new technique, gain switching inside the transducer has been introduced to obtain the best working condition for the measurement setup

<u>Multidrop or distributed multiplexing</u>
A charge to DeltaTron® adaptor has been developed with identification in accordance to IEEE P1451.4. It contains TEDS and extended functionality such as dual gain and multidrop facilities. The content of the TEDS is shown in Fig. 6. Multidrop means that several charge to DeltaTron adaptors can be used on the same MicroLAN™ network as a serial, distributed multiplexer. The main application is to allow charge accelerometers (which are analogue transducers) to communicate digital information with an IEEE1451 capable instrument. There are three modes of operation; two gain settings of 1,0 mV/pC and 10,0 mV/pC and an “analogue off” mode which is used to implement the multiplexer function

<u>Analyzer TEDS Support</u>
The B&K PULSE Analyzer is the first analyzer platform to fully support standardized TEDS not only from the initial setup but right through to the analysis result. The system automatically detects the connected transducers, and sets their sensitivities, thus ensuring the correct conditions are always used when making measurements. You can thus have complete confidence in the final data.
An example of the PULSE system with a Modal Shaker application is shown in Fig. 7. A number of windows are opened to show the resulting set-up after connection of a tri-axial transducer and a "Get configuration" command. The proper transducer channels are shown in the configuration and the associated sensitivities are used in the channels. The transducers can also be found in the database.

<u>Automated set-up of preamplifiers</u>
The B&K NEXUS range of accelerometer and microphone preamplifiers communicates with the transducers and the received information is used to set up the preamplifier correctly. The data can also be sent on to a controlling computer.
The Endevco Optimal Architecture Sensor Interface System OASIS-2000 is a modular system consisting of a 16 Rack Enclosure that can be fitted with up to 128 channels per rack to provide power, computer control and signal conditioning. One of the input modules is an eight channel card Model 482 that supports IEEE 1451.4 and features automatic transducer identification and user-defined output normalization.

CONCLUSION

The measurement community is best served with transducers with integrated identification and data. The work in the IEEE working group and in the involved companies has in a short time brought Plug and Play to the measurement community and thereby helped the transition to larger systems with more transducers, and simultaneously introduced a new level of quality into the measurements.
The authors would like to take the opportunity to encourage both users and transducer manufacturers alike to participate in the discussions of the standard which is now in the last stage of finalization (for the P1451.4) to ensure that the coming IEEE standard is designed to fit their needs.

REFERENCES

1. “IEEE Std 1451.1-1999, Standard for a Smart Transducer Interface for Sensors and Actuators - Network Capable Application Processor (NCAP) Information Model,” Institute of Electrical and Electronics Engineers, Inc., Piscataway, New Jersey 08855, June 25, 1999.
2. “IEEE Std 1451.2-1997, Standard for a Smart Transducer Interface for Sensors and Actuators - Transducer to Microprocessor Communication Protocols and Transducer Electronic Data Sheet (TEDS) Formats,” Institute of Electrical and Electronics Engineers, Inc., Piscataway, New Jersey 08855, September 26, 1997.

3. “A mixed-mode smart transducer interface for sensors and actuators”, S.Chen and K.Lee, Sound & Vibration, April 1998.
4. Impact of the proposed IEEE 1451.4 Standard for transducers on future measurement systems. S.Chen, J. Bække, T. Licht, SensorExpo Conference, Anaheim, CA, USA, 2000.
5. Practical applications of integrated transducer communication, B. Ginn, J. Bække, H. Larsen, B. Kriegbaum, Internoise 1998.
6. Bringing plug and play into multichannel systems using transducers with integrated identification, J. Bække, H. Larsen, B. Kriegbaum, B. Ginn, WATTec98, Knoxville, TN, USA.
7. Woods, Stan *et al*. “IEEE-P1451.2 Smart Transducer Interface Module,” Proceedings Sensors Expo Philadelphia, pp. 25-38, October 1996, Helmers Publishing.
8. Johnson, Robert. “Building Plug-and-Play Networked Smart Transducers,” Sensors Magazine, pp. 40-46, October 1997, Helmers Publishing.
9. Warrior, Jay. “IEEE-P1451 Network Capable Application Processor Information Model,” Proceedings Sensors Expo Anaheim, pp. 15-21, April 1996, Helmers Publishing.
10. Lee, Kang, Schneeman, Richard. “Distributed Measurement and Control Based on the IEEE 1451 Smart Transducer Interface Standards,” Instrumentation and Measurement Technical Conference 1999, Venice, Italy, May 24-26, 1999.

NOTE:
ICP® is a registered trademark of PCB Piezotronics, Inc.
DeltaTron® is a registered trademark of Brüel & Kjær Sound and Vibration
IsoTron® is a registered trademark of Endevco Corporation
MicroLAN™ is a trademark of Dallas Semiconductor

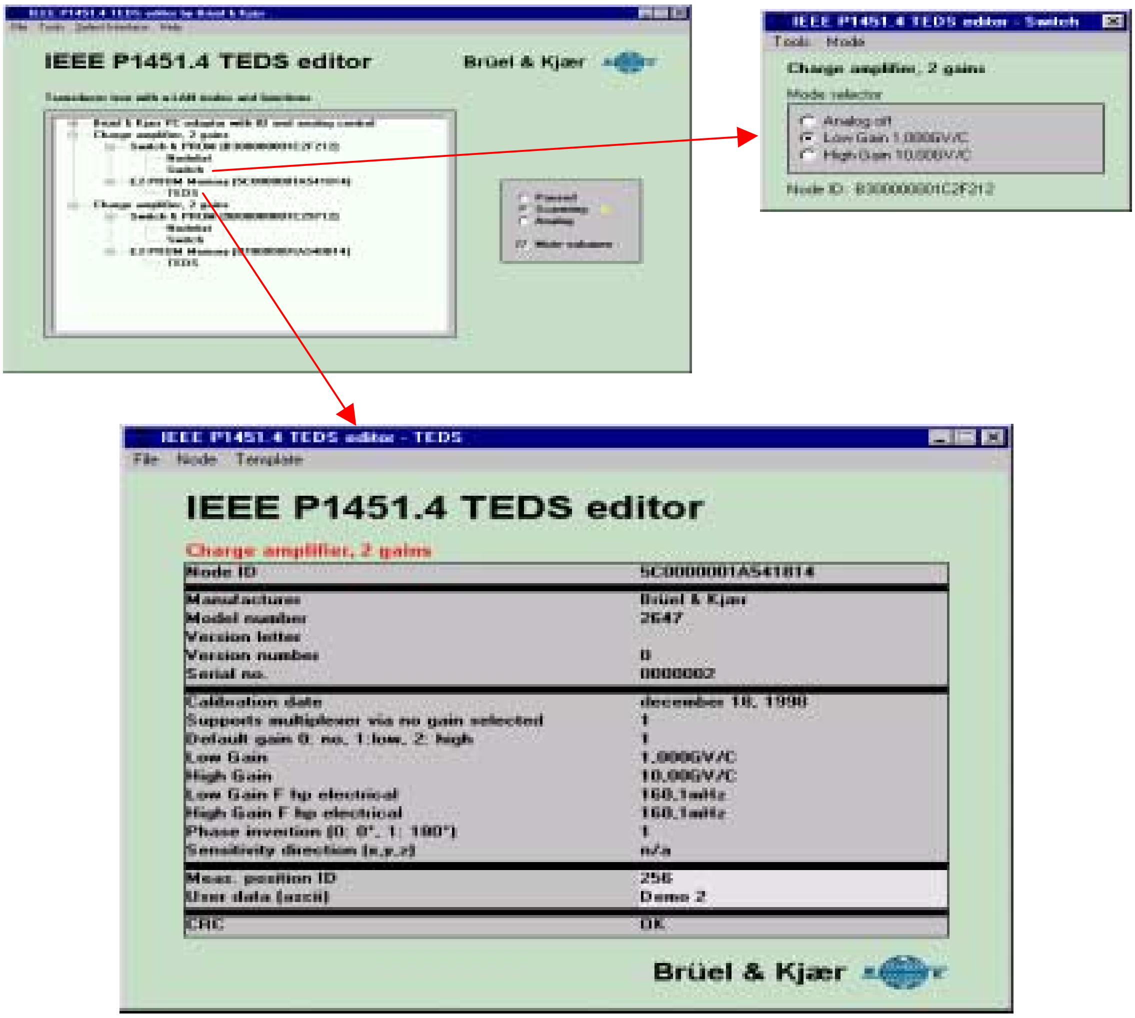

Fig. 6. Example of IEEE P1451.4 TEDS editor for a Charge to DeltaTron converter showing the three main areas of the memory (the "fixed" identification field, the "variable" transducer specific template and the "free" comments field). Top left shows the tree structure of the transducer configuration. Top right: the mode selector.

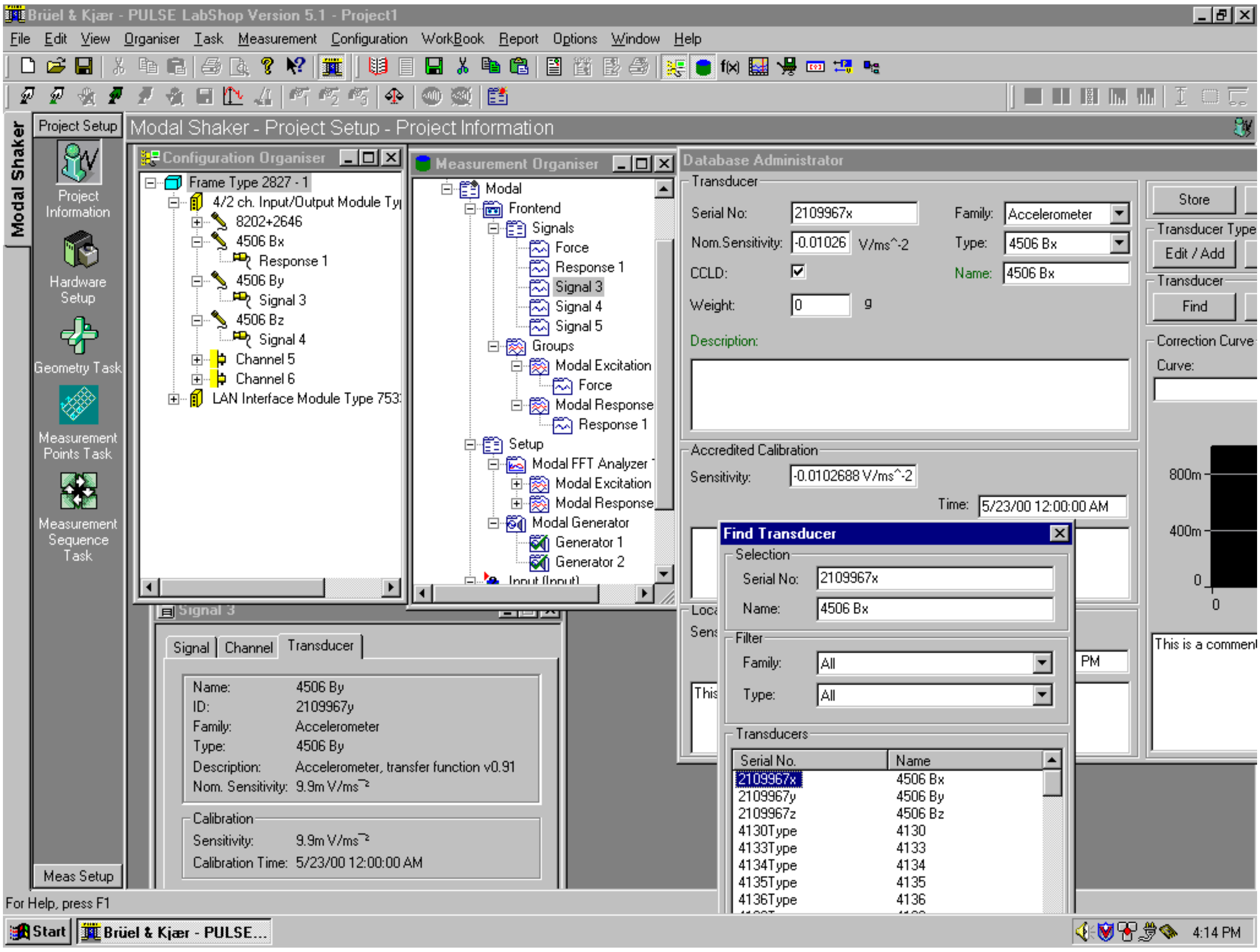

Fig. 7. PULSE MODAL SHAKER application. A number of windows are opened to show the resulting set-up after connection of a tri-axial transducer and a "Get Configuration" command. The proper transducer channels are shown in the configuration and the associated sensitivities are used in the channels. The transducers can also be found in the database.